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MATURATION OF WESTERN LARCH CONES AND SEEDS

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CONTENTS

	Page
INTRODUCTION	1
METHODS	1
RESULTS	4
Cone Ripening and Ripeness Indicators	4
Seed	7
DISCUSSION AND CONCLUSIONS	13
PUBLICATIONS CITED	15

RESEARCH SUMMARY

Weekly cone collections from late July through September 1964 and 1965, and irregular collections in 1966 and 1967 were used to evaluate specific gravity and moisture content as indices of cone maturity. Although both indices decreased with advancing cone maturity, neither index gave a firm indication of seed maturity, but they did predict when cones would open. The ratio of embryo length to embryo cavity length gave the best estimate of seed maturity in 1964. Cones on a given tree all open within a short period of time, but the opening of cones among individual trees within a stand may vary greatly. Larch cone collections can begin in mid-August; if cones are stored under well-ventilated conditions for several weeks before seeds are extracted, viability remains high.

INTRODUCTION

Western larch (*Larix occidentalis* Nutt.), a conifer prized for its beauty and timber value, grows in the Northern Rocky Mountains west of the Continental Divide. Larch cones are small and widely scattered throughout the crowns, making collection both difficult and time consuming. Good cone crops, with higher than average seed viability (Shearer 1959), occur on the average of every 5 years (range of 1 to 12 years). Usually, a concerted effort is made to collect these cones during years of abundance to supply the needs for seeding and planting during intervening years of scarcity.

Specific gravity and moisture content are successfully used to identify seed maturity in other conifers: true firs (Franklin 1965; Pfister 1967; Oliver 1974); pines (Eliason and Hill 1954; Krugman 1966); and spruce (Cram 1956; and Cram and Worden 1957). Other indices have been used: cone firmness, color, and seed brittleness (Crossley 1953); and reducing sugar content of seed (Rediske 1961, 1969); crude fat concentration (Rediske and Nicholson 1965); ratio of embryo length to embryo cavity (Oliver 1974); and seed weight (Olson and Silen 1975).

The purpose of this study was to identify a reliable index (specific gravity, moisture content, cone color, and embryo length) of western larch seed maturity and to determine if the period of cone collection (usually from late August through mid-September) could be extended. In addition, some possible climatic factors influencing cone maturation and seed viability were investigated.

METHODS

Five western larch trees varying in age from 55 to 70 years were selected in July 1964 for sampling (fig. 1). The trees grow on gentle, northerly facing slopes at about 4,000 feet in elevation on the Lolo National Forest in lower Pattee Canyon near Missoula, Montana. They varied in diameter from 8.6 to 11.6 inches and in height from 50 to 64 feet. Selection was based on: (1) each tree having at least 300 cones; (2) a range of cone colors--two trees with deep reddish-brown cones, two trees with green cones, and one tree with brown cones (a second tree with brown cones was not found); and (3) dominant trees that were easily climbed with ladders.

Figure 1.--Tree G-1 in mixture with Douglas fir, ponderosa pine, and other western larch

Table 1.--*Number of cones from each of the five study trees used to derive the following data by year*

Data	Year of cone collection[1]			
	1964	1965	1966	1967
Specific gravity (SG)	18	5	0-5	6
Moisture content (MC)	4	5		
Weight per 1,000 seeds (grams)	21	4-9	0-5	6
Germination (percent)	21	4-9	0-5	6
Average seeds per cone	21	4-9	0-5	6
Seed extracted after cone storage	7	4-9	0-5	6
Seeds per SG class	14			
Seed wt. per SG class (grams)	14			
Frequency distribution of SG	14			
Seed extracted on day cones were collected	14			

[1]Number of collection dates: 1964, 11; 1965, 7; 1966, 1; 1967, 6.

The trees were sampled from 1964 to 1967 to study yearly variation in the cone maturity and time of seed release. Table 1 shows the data derived by year of cone collection and the number of cones sampled.

At each collection, cones free from visible insect damage were picked randomly throughout the crown of each tree. The cones were placed in plastic bags to reduce moisture loss and taken immediately to the laboratory.

For all cones collected, specific gravity was determined from the loss in weight of each cone in water. Samples of the cones collected in 1964 and 1965 were ovendried at 212° F for 20 hours and moisture content was calculated.

In 1964 over half the cones collected each week were segregated into specific gravity classes and dried for 24 hours at 113° F. Seed was then extracted in each class by shaking the cones. The seeds were dewinged, weighed to the nearest 0.001 gram, and counted. For each specific gravity class, weight per 1,000 seeds and the average number of extracted seeds per cone were calculated. The seeds were kept in envelopes at room temperature until the germination tests.

Depending on the year, some or all the cones were stored in well-ventilated paper sacks in a cool, dark room until the fall or winter, when they were dried for 24 hours at 113° F and the seeds extracted, dewinged, and weighed to the nearest 0.001 gram. The average number of seeds per cone and weight per 1,000 seeds were calculated for each group of cones. The seeds were kept in envelopes at room temperature until the germination tests. In 1976 ratio of embryo length to cavity length was determined from residual 1964 seed that was stored in the envelopes.

Differences in seed viability caused by variation among the five trees, the 10 collection dates, and the two extraction times were determined in germination tests that were replicated three times. Seeds were evenly spaced on blotter paper in petri dishes (100 seeds per dish) when there was enough seed. The seeds were moistened thoroughly with water then stratified at 35° F. The dishes were then arranged in a randomized block design and incubated at 80° F ± 1° F in constant, low-intensity, incandescent light. Germination (seeds with radicle emergence 0.1 in) was recorded

at irregular intervals. The nongerminated seed was then classified as sound, rotten, or empty.

The 1964 germination data were analyzed in a multivariate analysis of variance to determine the significance of the tree, collection date, and extraction time differences. Analysis of variance was used to analyze the germination data from 1965 and 1967; the 1966 data were not analyzed.

RESULTS

Cone Ripening and Ripeness Indicators

In 1964, the western larch cones increased in length and width through August 10, then decreased in these dimensions through the final collection. The cones ranged in length from 1.00 to 2.00 inches (average 1.42 inches) and in width from 0.60 to 1.05 inches (average 0.80 inch). Cone size differences by tree were consistent in the 4 years of study.

Changes in specific gravity, moisture content, and color all signaled the maturing of western larch cones through August and September. Climatic factors such as rainfall and temperature modified the time of cone opening.

Embryo Development

The megagametophytes were milky in late July but were firm by early August. As shown in the following tabulation, embryo development (ratio of embryo length to cavity length) was complete by mid-August for all seeds; embryos in seeds from three of the five trees were fully developed by early August:

1964 date	*Average* Percent	*Standard deviation* Percent
July 29	83	2
August 3	86	5
August 10	95	4
August 17 and 24	99	1
August 31 to September 28	100	0

Specific Gravity and Moisture Content

In 1964 and 1965, specific gravity (fig. 2) and moisture content of larch cones were closely related and remained relatively constant from late July to early September, then decreased rapidly through the final measurement at the time of seedfall. Correlation values for these 2 years ranged from $r = 0.94$ to $r = 0.99$ for individual trees, with a pooled $r = 0.99$ (fig. 3). Because of this close correlation, only specific gravity was determined for the cones in 1966 and 1967.

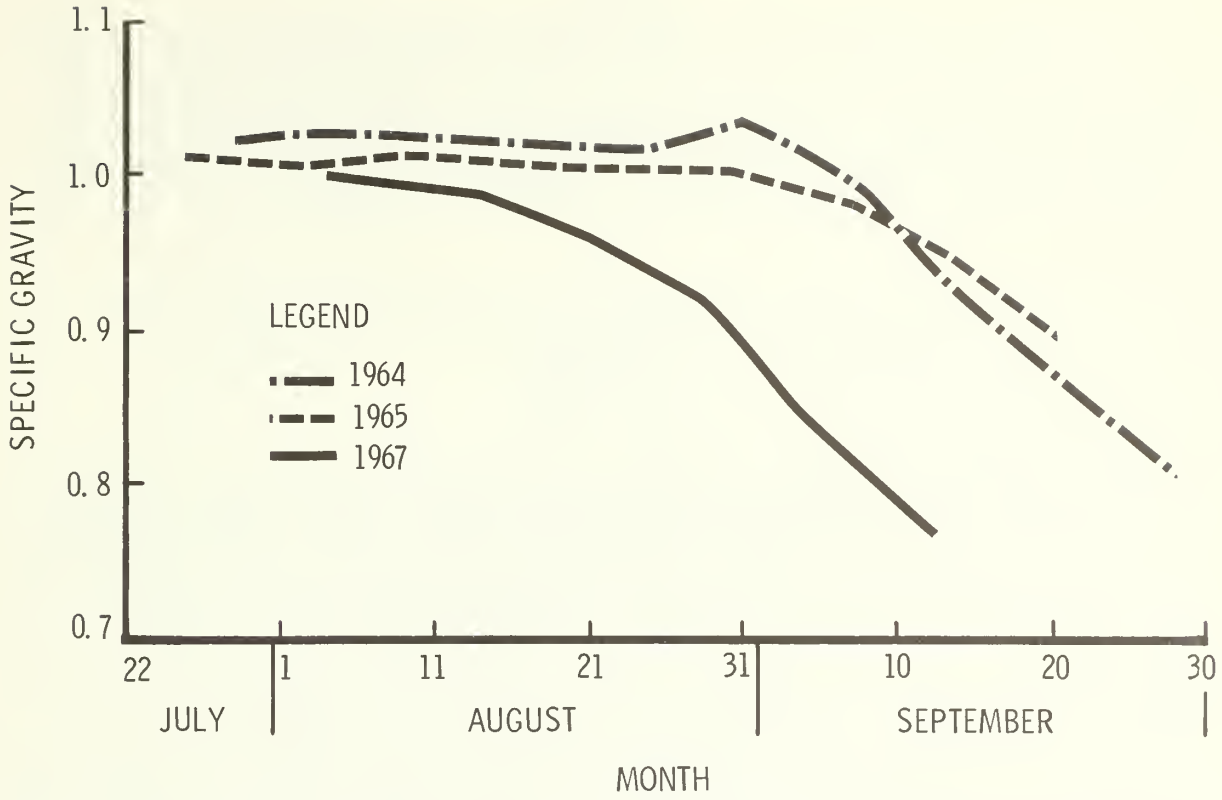

Figure 2.--Average cone specific gravity by collection date; 1964 and 1965 were wet years, 1967 was a dry year.

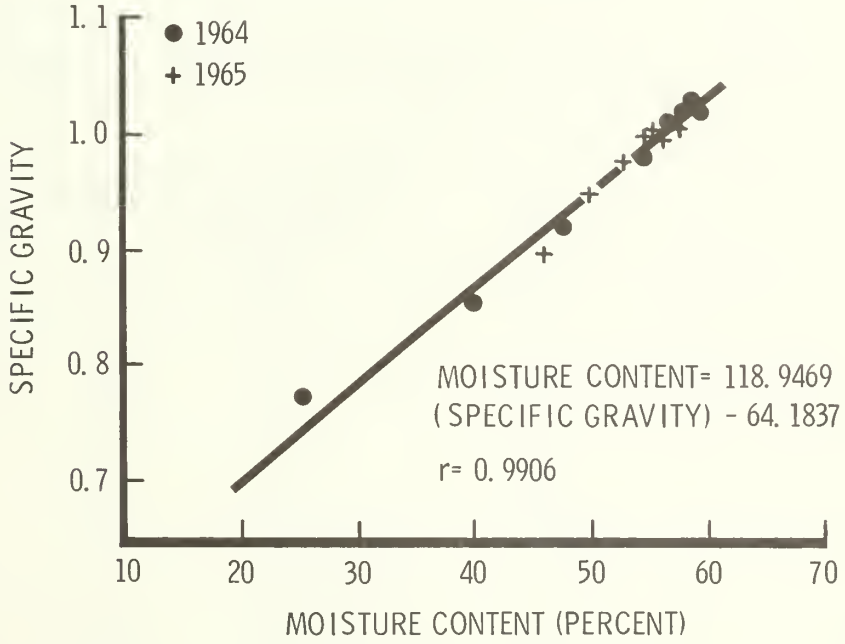

Figure 3.--Relationship of specific gravity to moisture content of western larch cones harvested in 1964 and 1965.

The variation in specific gravity and moisture content among the cones in August was small but increased rapidly as the cones dried in September. Most of the variance in the September data resulted from between-tree rather than within-tree differences. Specific gravity of cones decreased at a rate that was characteristic of each tree regardless of year. Trees with cones that decreased in specific gravity most rapidly also began seedfall earliest. Moisture content of the cones ranged between 55 and 60 percent throughout August then decreased rapidly in September.

Cone Color

As cones matured and finally opened, they lost the reddish or greenish hues and became more yellow or brown. At the time of seedfall cones collected from these five trees were nearly the same color.

Climatic Influence

The rate of decrease in cone specific gravity and moisture content during August and September prior to cone opening was influenced by the amount and frequency of rain and the average air temperature or heating degree-days. (One heating degree-day is here defined as a day on which the mean daily temperature is 1 degree below 65° F.) Above-average rainfall and below-average temperature (higher number of heating degree-days) characterized the summers of 1964 and 1965, whereas below-average rainfall and above-average temperature (lower number of heating degree-days) typified the summer of 1967 (table 2). Specific gravity decreased more rapidly during the hot, dry summer of 1967 than in the cooler, moister summers of 1964 and 1965 (fig. 2). The difference in specific gravity between 1964 and 1965 was not statistically different. However, the release of seed occurred later in September 1965 than in 1964; greater rainfall and lower temperature (more heating degree-days) were recorded in September 1965 than in 1964. An exact comparison between those 2 years was not possible because insufficient numbers of cones were produced in 1965 to permit collections until cones had opened.

Table 2.--*Temperature and precipitation patterns at the National Weather Service Station, Missoula, Montana, by year*

Year	Month	Precipitation		Temperature		Heating degree-days	
		Amount	Departure from normal	Mean	Departure from normal	Sum	Departure from normal
		Inches	*Inches*	*°F*	*°F*		
1964	July	0.94	+0.09	66.2	-0.8	31	- 3
	August	1.84	+1.12	60.8	-4.0	153	79
	September	.51	- .51	51.1	-4.3	409	106
1965	July	1.59	+ .74	65.0	-2.0	44	10
	August	2.24	+1.52	64.1	- .7	88	14
	September	2.11	+1.09	47.8	-7.6	509	206
1967	July	.40	- .45	70.0	+3.0	2	- 32
	August	Trace	- .72	71.2	+6.4	4	- 70
	September	.49	- .53	62.2	+6.8	116	-187

SEED

Seedfall

Western larch cones on the trees opened in late summer at a specific gravity of 0.80 to 0.85 and a moisture content of 35 to 40 percent. Usually all the cones on a tree opened within a week of one another. However, considerable variation occurred between trees, as shown for 1964 and 1967, by date cone opening was first observed:

Tree	*1964*	*1967*
G-1	September 14	August 28
R-1 and I-1	September 21	September 4
G-2	September 28	September 12
R-2	After October 1	After September 12

Cones on tree G-1 opened about a week before cones on trees R-1 and I-1; cones on trees G-2 and R-2 opened still later as shown in the tabulation. Cones on all trees opened about 2 weeks earlier in 1967 than they did in 1964. In 1965, sampling depleted the cone crop prior to seedfall. Left on the trees, cones probably would have begun seed dispersal about a week later than in 1964. In 1966, only enough cones were produced for one collection.

Number and Viability

The number of seeds extracted from the cones and their viability were dependent on at least three factors: (1) location or possible inherent characteristics of the parent tree; (2) stage of maturity when cones were picked (table 3, fig. 4); and (3) the length of time between cone collection and seed extraction (table 4 [compare means], fig. 5).

Tree differences.--The average number of seeds extracted per cone varied by tree (table 3). Consistently fewer seeds were extracted from cones of tree G-1 than from the other trees. The scales on cones picked from tree G-1 failed to fully open; scales on the cones picked from the other trees opened easily. These characteristics were also consistent among cones picked from the trees in 1965, 1966, and 1967.

Table 3.--*Mean number of seeds per cone extracted on October 30, 1964, by date cones were picked*

Collection date, 1964	Mean	Range	Standard deviation
July 29	62	91-33	28
August 3	70	84-39	18
10	75	90-41	21
17	86	105-57	18
24	80	95-63	13
31	86	98-71	10
September 8	100	113-88	10
14	103	115-87	13
21	89	102-63	16
28	72	104-56	29

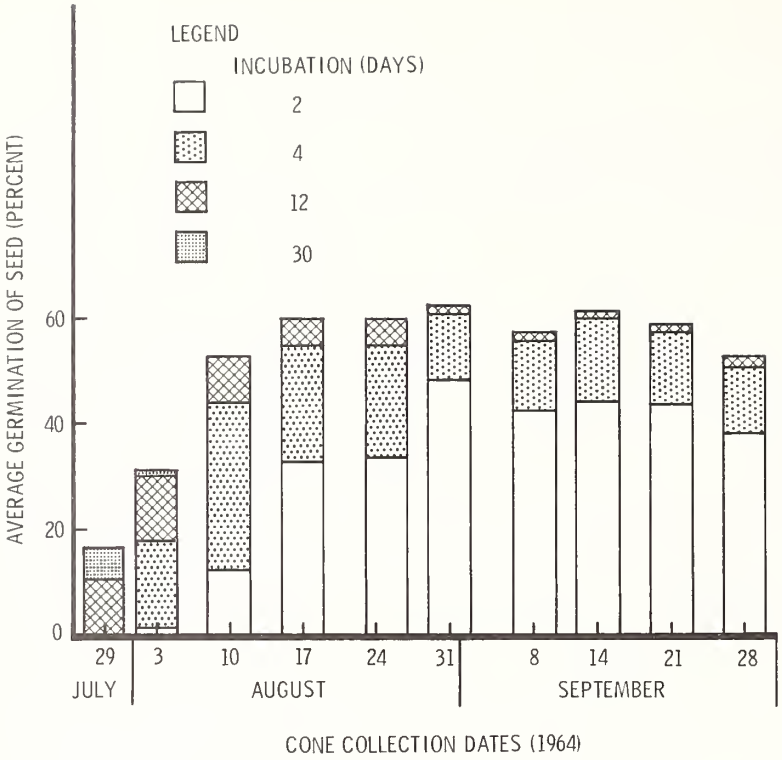

Figure 4.--Effect of cone collection dates on germination of western larch seed extracted October 30, 1964; 2, 4, 12, and 30 days after the start of incubation.

Table 4.--*Average number of western larch seeds per cone extracted the day of collection by specific-gravity class at 10 weekly intervals in 1964*

Cone specific gravity	7/29	8/3	8/10	8/17	8/24	8/31	9/8	9/14	9/21	9/28
	Number									
1.070 to 1.099						73				
1.040 to 1.069	41	40	71	80	90	75	100			
1.010 to 1.039	25	55	52	52	89	74	101	90		
0.980 to 1.009	37	8	24	35	74	62	89	80	103	
0.950 to 0.979							85	84	100	
0.920 to 0.949							87	72	90	93
0.890 to 0.919							81	70	98	91
0.860 to 0.889							105	57	98	91
0.830 to 0.859								50	92	97
0.800 to 0.829								36	81	
0.770 to 0.799								60	69	91
0.740 to 0.769								80	51	93
0.710 to 0.739								46	71	79
<0.710									72	80
Average	29	49	49	50	84	72	91	71	88	90
Average number of seed from cones stored until October 30	62	70	75	87	80	87	100	103	89	72

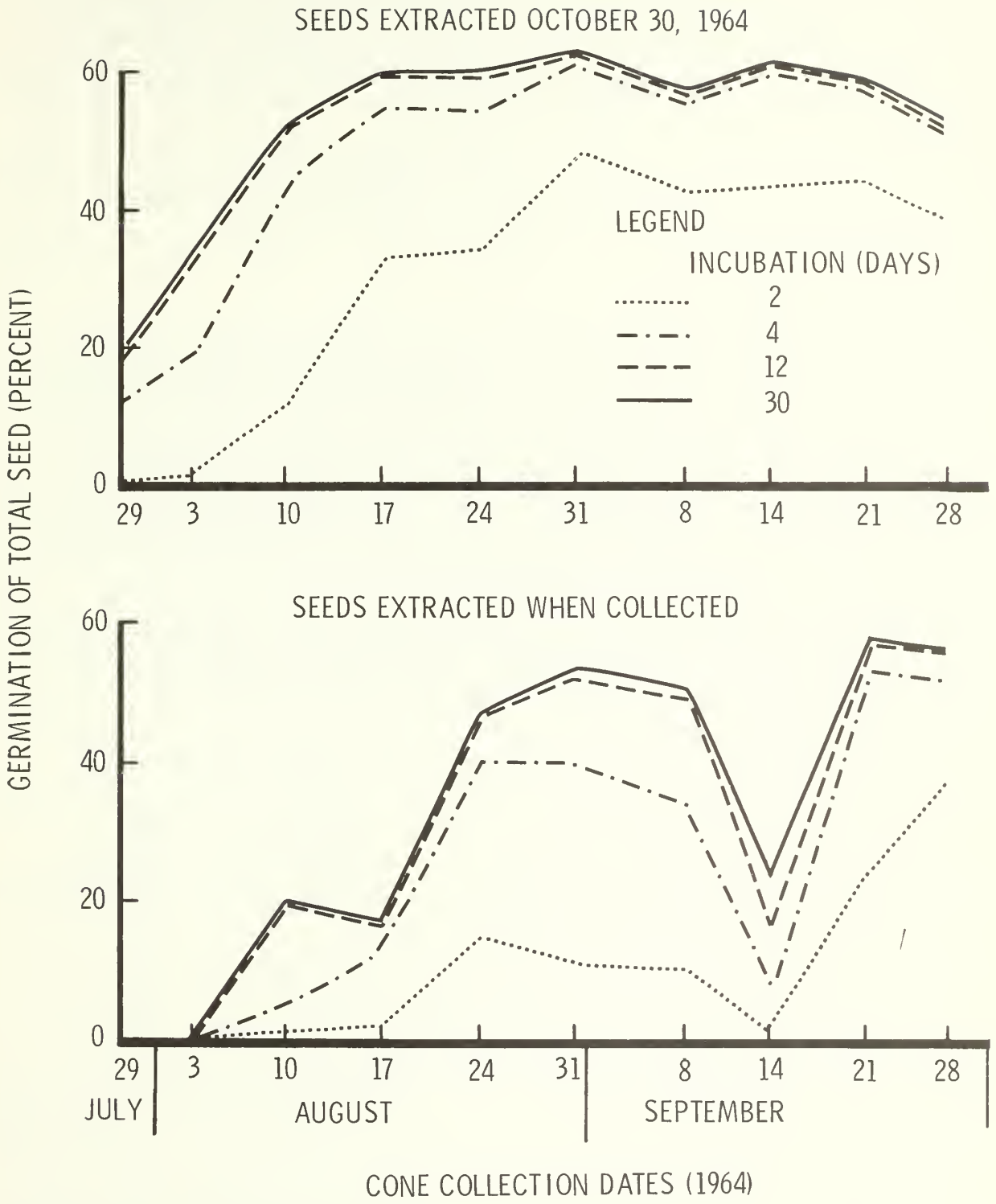

Figure 5.--Effect of extraction time and collection date on germination of western larch seed; 2, 4, 12, and 30 days after the start of incubation.

As shown in the following tabulation, the greatest germination of seed collected in 1964, 1965, and 1967 from the five western larch trees averaged 55 percent and ranged between 79 and 35 percent (standard deviation, 13 percent). Seed viability from the trees fell into two groups. Three trees, growing within 500 feet of one another, averaged 62 percent germination (standard deviation, 12 percent) in the 3 years. The other two trees grew within 100 feet and averaged 44 percent germination (standard deviation, 7 percent) during the same period.

	Year of collection			
	1964	*1965*	*1967*	*Average*
	- - - - - - - *Percent* - - - - - - - -			
Average	66	49	50	55
Standard deviation	14	10	9	13

Date of cone collection.--The number of seeds per cone extracted after storing the cones until October 30, 1964, generally increased from the July 29 through mid-August collections--one tree through early September (table 3). Cones picked from two trees on July 29 opened poorly and most seeds were trapped inside. The low number of seeds shown in table 3 from September 14 to 28 probably resulted from the loss of some seeds prior to picking the cones. (Larch cone scales open and close easily, depending on humidity and temperature, and it is difficult to identify closed cones that previously opened). Some cones with below-average specific gravity and below-average seed yield were infested by insects that prevented the scales from flexing normally and releasing the seeds. Heavy deposits of resin on scales of some cones also prevented normal release of some seed.

Viability of seed was also influenced by the date the cones were picked (fig.4). As shown in the following tabulation, trees with the highest seed viability (G-1, R-1, I-1) usually produced cones that matured earliest (collection date when seed reached at least 90 percent of the maximum germination recorded).

Tree identification	*Date of cone maturity by collection year*		
	1964	*1965*	*1967*
G-1	August 10	August 30	August 4
R-1	August 10	August 30	August 21
I-1	August 10	September 7	August 4
G-2	August 17	September 7	August 28
R-2	August 24	September 7	August 21

This tabulation also shows that the date of cone maturity varied by year; i.e., cones matured in mid-August in 1964 and 1967 and in early September in 1965.

Total germination and germinative energy (percentage of seeds that germinated within 4 days) increased through the August 31 collection (fig. 4). The average germinative energy was very poor from July 29 collections, but total germination varied widely by parent tree (R-1, 61 percent; G-1, 32 percent; I-1, 20 percent; G-2, 8 percent; and R-2, 0 percent). Similar trends occurred in 1965 and 1967 except highest germination in the 1965 seed occurred in seed collected 2 weeks later than in 1964.

Time of extraction.--Seed quantity and quality were not only influenced by when the cones were picked but also by when the seeds were extracted from the cones. In 1964, cones dried the same day picked usually yielded fewer seeds than the cones stored until October 30. Cones picked July 29 did not open fully, especially when seeds were

extracted immediately. This problem persisted through August 17 (the next three collections) among cones dried without storage and through August 10 (the next two collections) among cones stored until October 30. The number of seeds released from the cones picked on any one date usually declined with decreasing cone specific gravity (table 4), because some lighter cones had already shed some seed.

Considerable variation existed between trees in the release of seed from cones stored until October 30. For example, seed release from cones of tree G-1 was low (31 seeds per cone) from the July 29 collection and increased slowly each subsequent week to a high of 88 seeds per cone from the September 8 collection. Seed release started low (33 seeds per cone) for tree R-1 but by August 17 released over 80 seeds per cone. The remainder of the trees produced cones that readily opened after all collections.

A trend of increasing seed weight with increasing specific gravity is apparent in table 5. Seed weight increased until mid-August, then declined. Seeds extracted from cones the day of collection were heavier than seeds extracted from cones collected the same day but stored until October 30.

Storage of cones prior to extraction prolonged the maturing processes in the seed and increased its viability when compared to seed extracted the day of cone collection (fig. 5). Total germination and germinative energy of seed extracted the day the cones were picked was significantly reduced except for the last two collections of 1964. Cones collected on July 29 and August 3, 1964, from trees other than tree R-1 yielded seed of low viability regardless of when the seed was extracted. Seeds extracted immediately following the cone collections on July 29 and August 3 had less than 1 percent germination. Cones collected on July 29 but stored until the end of October yielded seed that varied in viability from no germination (tree R-2) to 46 percent germination (tree R-1). The drastic decline in viability of seed collected and extracted on September 14 is unexplained. The 1964 data suggest that cones collected mid-August and stored were sufficiently mature to provide seed comparable in viability to cones collected later. As a result of the comparison in 1964, all cones were stored in 1965, 1966, and 1967.

Table 5.--*Weight of western larch seeds extracted the day of collection by specific-gravity class at 10 weekly intervals in 1964*

Specific gravity class	7/29	8/3	8/10	8/17	8/24	8/31	9/8	9/14	9/21	9/28	Weighted mean
	Grams per 1,000 seeds										
1.070 to 1.099						3.60					3.60
1.040 to 1.069	3.34	3.14	3.33	3.49	3.59	3.48	3.27				3.45
1.010 to 1.039	2.93	2.94	3.23	3.54	3.41	3.27	3.15	3.34			3.25
0.980 to 1.009	2.68	2.74	3.10	3.11	3.17	3.05	3.17	3.36	2.73		3.11
0.950 to 0.979							3.08	2.97	2.99		2.99
0.920 to 0.949							3.07	3.39	3.20	3.14	3.19
0.890 to 0.919							2.81	3.45	3.26	3.06	3.26
0.860 to 0.889							2.93	3.28	3.14	3.34	3.17
0.830 to 0.859								3.11	3.13	2.89	3.09
0.800 to 0.829								3.41	3.14		3.19
0.770 to 0.799								3.23	3.16	2.75	3.01
0.740 to 0.769								3.03	2.53	3.02	2.96
0.710 to 0.739								2.68	2.81	2.99	2.83
<0.710									2.50	2.72	2.78
Weighted mean	2.88	2.97	3.14	3.46	3.45	3.35	3.14	3.28	3.10	3.01	

Germinative energy was also substantially increased by storing the cones picked from July 29 through August 17, 1964, (fig. 5). Seed extracted on July 29 and August 3 failed to germinate, seeds extracted August 10, August 17, and September 14 has low germination, and seeds extracted on all other dates had near normal germination. Seed from cones collected August 10 or later and stored had similar germination (fig. 5).

For seeds extracted October 30, 1964, the incidence of seed decay among ungerminated seed at the completion of the germination test was lowest from cones collected on August 17 or later (fig. 6). The time of extraction made little difference for the September cone collections except for the unexplained drop in viability of the seeds (and a corresponding increase in decay) collected on September 14.

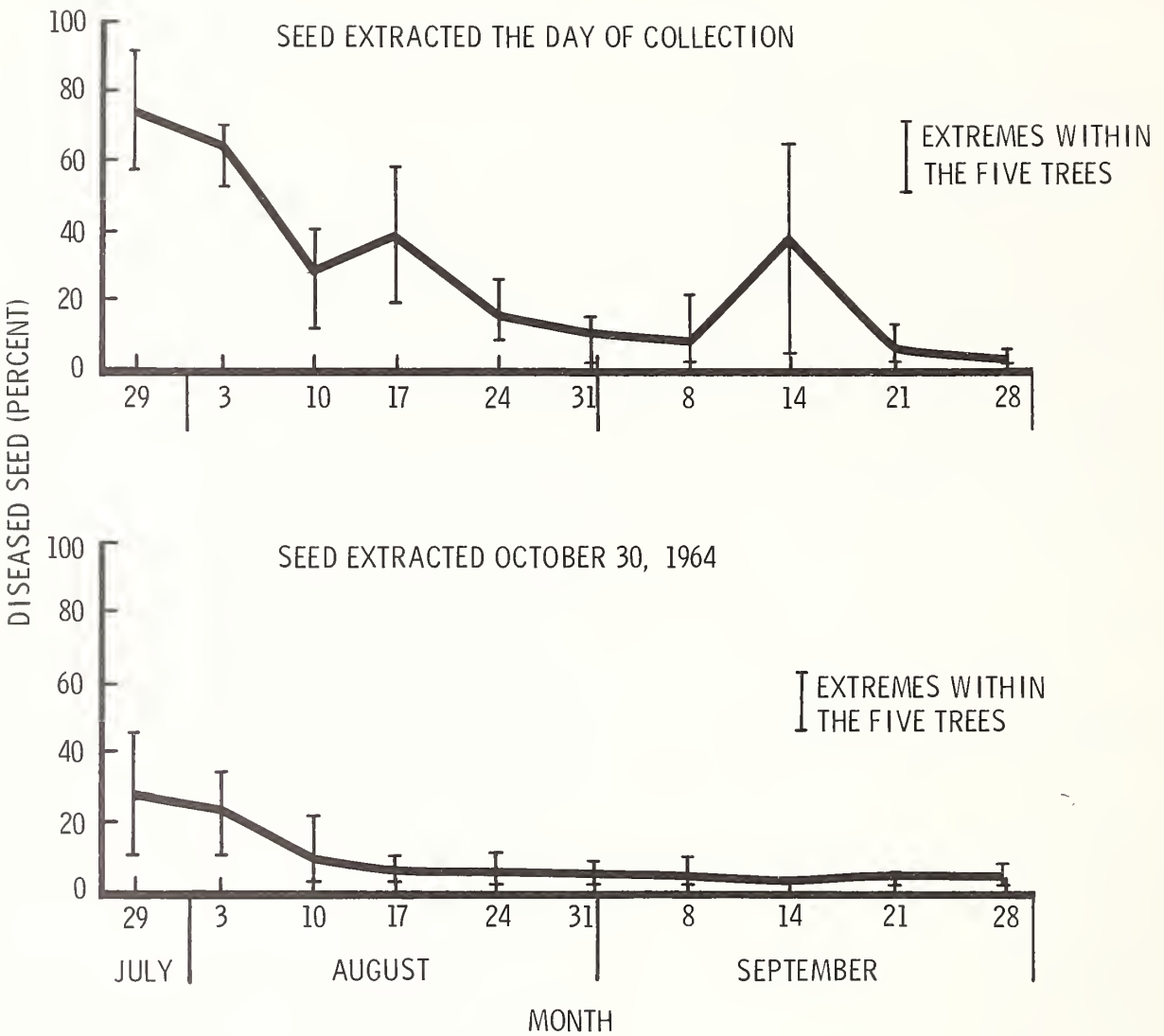

Figure 6.--Average percent of ungerminated seed from five trees that were classified as "diseased" at the completion of the germination test by cone collection date and when seed was extracted.

Table 6.--*Average weight of air-dried seeds extracted from stored cones of five western larch trees at varying intervals in 1964, 1965, 1966, and 1967*

Collection year	July 26-31	Aug 1-7	Aug 8-14	Aug 15-21	Aug 22-28	Aug 29 - Sep 4	Sep 5-11	Sep 12-18	Sep 19-25	Sep 26
	Grams per 1,000 seeds									
1964	2.47	2.82	3.01	3.13	3.04	3.14	3.03	3.02	2.99	2.82
1965	2.33	2.65	--	--	2.44	2.66	2.86	2.88	2.88	--
1966	2.14	--	--	--	--	--	--	--	--	--
1967	--	2.18	2.37	2.50	2.50	2.72	--	2.48	--	--

Seed weight.--Weight (grams per 1,000 seeds) of seeds extracted the day of cone collection varied by collection date and specific gravity of cones (table 5). The greatest seed weight was achieved near the end of August. At any given cone collection date, the heavier seeds were usually extracted from cones with high specific gravity.

Seed extracted from cones that were stored until October 30, 1964, average 93 percent as heavy as seeds extracted the day of cone collection (table 6--compare 1964 data with weighted means shown in table 5). Seed extracted from cones in subsequent years were lighter than seeds extracted in 1964.

DISCUSSION AND CONCLUSIONS

Many factors (natural and man-influenced) combine to affect the amount and quality of western larch seed collected. The continual demand for quality seed together with its high cost dictates that cones be collected during the infrequent years of heavy production when seed is mature, but prior to cone opening.

The rate at which cones mature is influenced by the average temperature during the growing season. Cones mature faster during summers of above-average temperature (such as 1967) than in summers of below-average temperature (1964 and 1965). Once the cones mature, prolonged periods of rain or high humidity can delay cone opening.

The ratio of embryo length to cavity length in 1964 gave the best indication of seed maturity. This has also been shown for true firs (Pfister 1967; Oliver 1974).

Based on 3 years of data, specific gravity and moisture content do not accurately indicate when cones are sufficiently mature to pick. These indicators did accurately predict when cones were to open (specific gravity about 0.820, moisture content about 35 percent). Because of the wide range in cone colors within and among individual trees as cones mature, color is a poor indicator of cone maturity.

Larch cones can be picked from about mid-August and yield high viability seed if the cones are stored under well-ventilated conditions for a few weeks prior to seed extraction. This allows 3 to 6 weeks for collection prior to cone opening. Because mold is a severe problem in storing cones, particularly immature cones, sacks should be spaced so that air can circulate between them. If seeds are to be extracted immediately, cone collection should be deferred until about September 1.

Trees bearing "early-opening" cones begin to disperse seed 2 to 3 weeks before trees bearing "late-opening" cones. The cones on any given tree all open within a short time, perhaps within a week. Because only five trees were sampled, it was not evident if cone opening within a stand followed a normal curve or was skewed. Seed dispersal studies in western larch forests have shown that most sound larch seed is dispersed by mid-October. Seeds dispersed later usually have low viability and come from either the base or the apex of the cone.

Seed yield and viability are dependent on maturity of cones at harvest. When seeds were extracted the day of cone collection, both seed yield and viability increased from July 29 through August 31, 1964. However, when seed extraction was delayed until October 30 for each of these same collections, the number of seeds recovered and their viability were further increased. When seed must be extracted immediately following cone collection, then the late-August or early-September collections are best.

Germination tests showed that stored cones yielded seed of higher viability and less subject to disease during germination than seed extracted immediately following cone collection. Further, total germination was nearly the same for seeds collected at any date from mid-August until cone opening but germinative energy was greatest from late August until cone opening. The number of viable seeds was influenced by location of the trees, possibly caused by differences in pollination. Greatest seed weight occurred in mid-August regardless of when seeds were extracted. As a result, harvest of high-quality seed could have begun at least a month before seedfall in 1964.

The consistently lower weight of seed extracted October 30 compared with seed extracted the day of cone collection indicates a decrease, possibly of carbohydrates or other nutrients, from the seeds while the cones were stored. The difference cannot be attributed to water loss because all cones were dried similarly. Rediske (1961) showed reducing sugar decreased as seeds matured in picked cones. In addition, seed weight in subsequent years was less than in 1964, probably a reflection of fewer sound seeds.

Further studies can identify the optimum length of time for cone storage to extract high quantity and quality seed.

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Cone maturity in western larch in western Montana was most accurately predicted by the ratio of embryo length to seed cavity length. Neither moisture content nor specific gravity proved to be an index of cone maturity; however, cones predictably opened at a specific gravity of about 0.820 and a moisture content of 35 percent. In western Montana cone collection can begin in mid-August. Permitted to mature for several weeks in mold-inhibiting storage, cones will yield high percentages of viable seed.

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